# A CRITICAL EVALUATION OF THE FACTORS INFLUENCING HIGH STRAIN RATE SUPERPLASTICITY

FINAL PROGRESS REPORT

TERENCE G. LANGDON

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UNIVERSITY OF SOUTHERN CALIFORNIA

Summary of the results obtained on this program

This research program was initiated in August 1996 with the two objectives of (1) conducting detailed experiments to provide a detailed understanding of the creep behavior of the metal matrix composites which are characteristic of high strain rate superplasticity (HSR SP) and (2) to endeavor to use a new processing technique, known as Equal-Channel Angular Pressing (ECAP), to achieve submicrometer and nanometer grain sizes in structural alloys and to use these materials to provide the first demonstration of HSR SP in conventional materials at relatively low temperatures. Both of these objectives were achieved during the life-time of this program and in the summer of 1999 the program was continued on a no-cost extension for an additional 6 months, up to January 2000, in order to provide an opportunity to bring the research to a satisfactory conclusion.

During the 3.5 years of this research program, a total of 47 papers was either submitted to the scientific literature or submitted for publication in conference proceedings. A complete listing of all of these papers is given in this report. Reprints of all publications have been submitted to ARO as they became available during the course of the program except only for publications #46 and #47 on the attached list which are currently in press and have been submitted only as preprints. There has been much interest in this work within the scientific community, especially in our use of the ECAP procedure, and in this respect it should be noted that the following 10 publications on the attached list are the publications arising from invited talks at national or international conferences: #7, 10, 14, 18, 21, 25, 31, 32, 41 and 47.

Full details of the results are given in the many publications documented herein. Briefly, the major findings in the first objective of this program may be summarized as follows:

(a) Metal matrix composites exhibit a creep behavior incorporating a threshold stress which can be easily deduced using a new extrapolation procedure.
(b) The creep rates within the metal matrix composites are governed by creep processes occurring within the matrix alloy.
(c) The creep rates in the composite may be influenced by the occurrence of a load transfer which serves to transfer some of the applied load to the reinforcement.
(d) By incorporating both load transfer and substructure strengthening into the analysis, it is possible to provide a consistent interpretation of both high temperature creep and high strain rate superplasticity and, in particular, it is possible to explain the anomalously high activation energies which are a consistent feature of HSR SP.
(e) Consistent results can be attained between powder metallurgy and ingot metallurgy metals when the threshold stresses are correctly incorporated into the analyses.
(f) The so-called substructure-invariant model for creep of metal matrix composites does not provide consistent results and must be discarded in favor of an interpretation of creep in terms of conventional climb and glide processes.

The second objective of this program led to remarkable success and, even within this short time-frame, a very clear demonstration that ECAP is a viable processing tool for achieving exceptionally small grain sizes and unusual material properties. The major findings of this part of the program may be summarized as follows:

(a) Equal-channel angular pressing is capable of achieving very substantial grain refinement, typically to the submicrometer level, in a wide range of materials.
(b) The ultrafine grains introduced by ECAP are formed in the first pass through the ECAP die in the form of subgrains separated by low angle boundaries, but subsequently these subgrain boundaries evolve into high angle boundaries as more dislocations enter the subgrain walls.
(c) In simple materials, such as pure metals and solid solution alloys, these ultrafine grains are not stable at the elevated temperatures which are needed for diffusion-controlled processes such as superplasticity, thereby precluding the possibility of achieving HSR SP in these materials.
(d) Ultrafine grain sizes may be retained at high temperatures, within the diffusion regime, when small precipitates are present within the matrix to restrict grain growth: this effect was illustrated for several alloys including a commercial Al-Mg-Li-Zr alloy and Supral-100 (Al-2004).
(e) It is possible to achieve HSR SP in non-superplastic Al-based alloys by subjecting the materials to ECAP and then deforming in tension at temperatures above one-half of the absolute melting temperature. Remarkable results were achieved with several alloys, thereby confirming the validity of this procedure.
(f) These results have the potential for transforming the superplastic forming industry. At present, this industry is restricted to the manufacture of low-volume high-cost components because of the low forming rates required for the fabrication process: but this may be transformed by using techniques such as ECAP to further refine the grain size into the submicrometer or nanometer range and thereby shift the strain rates associated with optimum superplasticity to much faster rates which will permit an opportunity for rapid forming.

Full details about these results, and their implications, are contained in the publications documented in the attached list. Further information is also available from the author of this report.

Participating scientific personnel:

P.B. Berbon (part-time graduate student on this program – now at Structural Metals Division, Rockwell Science Center, Thousand Oaks, CA).

S. Lee (graduate student on this program until January 2000 – scheduled to obtain Ph.D. degree during 2000).

Dr. Y. Li (Research Associate on this program – now at University of California, Irvine, CA)

Dr. B.Q. Han (Research Associate on this program until January 2000).

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Terence G. Langdon

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University of Southern California
Los Angeles, CA 90089-1453

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13. ABSTRACT *(Maximum 200 words)*

This Final Report lists the publications arising from this research program and also provides a brief description of the major findings. There were two major objectives of this program and both were fulfilled within the research period. These objectives were (1) to obtain a detailed understanding of the creep properties of metal matrix composites which are important in the field of high strain rate superplasticity and (2) to attempt to extend the range of materials exhibiting high strain rate superplasticity to commercial unreinforced alloys by using a new processing technique in which an ultrafine grain size is achieved by introducing severe plastic deformation. This latter objective has led to the first demonstration of superplasticity at very high strain rates and at relatively low temperatures in conventional materials.

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